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Heat Transmission in Rotary Kilns.—Part XII.

By W. GILBERT, Wh.Sc., M.Inst.C.E.

(263) In the calculations relating to the 200-ft. kiln and the 400-ft. kiln it was assumed that the raw material charge presented a plane surface for the reception of heat. In Part XI, however, the effect of lump size in the drying zone was considered, and it is now proposed to extend the inquiry to the decomposition zone. The advantage of a charge of 25 per cent. when dealing with relatively large lumps of material is also considered.

(264) It was shown in para. 247, Part XI, that each lump of material (assumed cubical in shape) passes through a series of heating cycles which each consists of

(*a*) A heating period on the lower arc, the time being fixed by the length of the arc and by the lining speed.

(*b*) Heating periods "on chord," the total time being less than the heating period on the lower arc in the ratio of the chord length to the arc length.

(*c*) Periods during which the material cube is buried in the remainder of the charge.

(265) During heating on the lower arc the rise of the surface temperature of the cube face which is in contact with the kiln lining is always considerable, and a definite calculation of it can be made.

Owing to the rapid circulation of the charge, heating on chord takes place during a number of equally spaced short intervals, but for calculation purposes the average rate of heat supply, assumed to be continuous, is used. The temperature difference thus set up between the surface of each cube and the centre is referred to as the "lump loss on chord." This loss is continuous.

There is also an intermittent lump loss due to heating on the lower arc. Each lump loss has to be determined before the rate of heat transmission per foot run of kiln can be obtained.

The length of a heating cycle is required in order to find out the rate at which each cube face takes in heat on chord. It also gives the time interval between

each heating on the lower arc, and it can thus be seen if the heat supplied to a cube face has been conducted to the interior before the same face comes on to the lining again.

(266) The effect of lump size is considered in relation to the 400-ft. kiln which was dealt with in Parts VI, VII and VIII. Stages (10) and (11) relate to the decomposition zone. The working conditions in each stage as regards the standard coal consumption, the gas velocity, composition, and temperature, and the material composition and temperature, remain unaltered.

Further details required for calculation purposes are given in Table XL, and the position of the decomposition zone is shown in *Fig.* 54.

TABLE XL.

EFFECT OF LUMP SIZE IN STAGES (10) AND (11)
PRELIMINARY DATA.

Line No.	Stage Number.		(10)		(11)	
	Charge per cent.		6	25	6	25
(1)	Kiln diameter inside lining ..	ft.	10.20	11.40	10.2	11.4
(2)	Length of upper lining arc ..	do.	25.14	22.65	25.14	22.65
(3)	Length of lower lining arc ..	do.	6.90	13.16	6.90	13.16
(4)	Length of material chord	do.	6.38	10.42	6.38	10.42
(5)	Charge volume per foot run ..	cu. ft.	4.90	25.52	4.90	25.52
(6)	Heat transmitted to material ..	per cent. on clinker	4.42	4.42	4.41	4.41
(7)	Flame temperature	deg. F.	2,450	2,450	2,450	2,450
(8)	Shell radiation factor		0.072	0.072	0.072	0.072
(9)	Density factor *F* for coke particles ..		0.67	0.67	0.87	0.87
(10)	Kiln speed (revolutions per minute) ..		1.00	1.00	1.00	1.00
(11)	Heating time on lower arc per cycle, minutes		0.215	0.368	0.215	0.368
(12)	Heating time on chord per cycle ..	do.	0.199	0.291	0.199	0.291
(13)	Conductivity of material in B.T.U. per square foot per hour, per degree Fah. per foot thick ..	K	0.725	0.725	0.800	0.800
(14)	Density of material (lb. per cu. ft.)	W	74	74	74	74
(15)	Specific heat of material	ϕ	0.25	0.25	0.25	0.25

Line (1).—The kiln diameter is increased in Stages (10) and (11) for a 25 per cent. charge in order to have the same area of gas way, and consequently the same coal consumption and clinker output, as for a 6 per cent. charge.

Lines (6) to (9).—These are taken from Table XXV, Part VIII.

Lines (11) and (12).—For method of calculation see Part XI, Appendix II.

Line (13).—The conductivity is given per foot of thickness, instead of per inch of thickness as previously.

Line (14).—The density given is that of the decomposed material.

(267) It is assumed that the material rises in temperature from 1,300 to 1,700 deg. F. during the decomposition process (see "The Theory of Cement Burning," by Dr. Hans Kühl, *Cement and Cement Manufacture*, November, 1930). It is also assumed that decomposition proceeds uniformly and symmetrically from the outside to the centre of a lump (see C. C. Furnas, "Rock Products," June, 1931).

(268) At the centre of Stage (10) one-fourth of the $CaCO_3$ is decomposed and the position is illustrated by *Fig.* 51. A cubical lump of side EF is drawn to scale, the inner cube of side GH representing the undecomposed material which is at a temperature of 1,400 deg. F. The volume of the inner cube is three-fourths of the outer cube, hence the ratio of the sides is as 1 to the cube root of 0.75, or as 1 to 0.91. Each face such as GH when maintained at decomposition temperature is assumed to be capable of absorbing heat as rapidly as it can be transmitted across the frustrum EFHG.

Let EF $= a$ and HG $= b$. For calculation purposes the frustrum may be replaced by an equivalent block of the same face area a^2 and of width y where

$$y = a^2 \left(\frac{1}{2b} - \frac{1}{2a}\right) \qquad \text{(13)}$$

If Q heat units pass per hour through the frustrum and the equivalent block, the temperature difference between the two faces EF and GH will be the same as the temperature difference between the front and back faces of the equivalent block. The latter quantity is easily calculated.

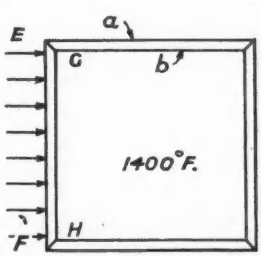


Fig. 51.

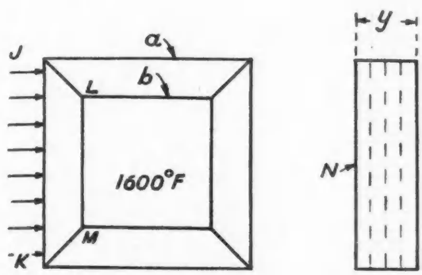


Fig. 52.

(269) At the centre of Stage (11) where three-fourths of the $CaCO_3$ is decomposed the position is illustrated by *Fig.* 52, which is also drawn to scale. The ratio of JK to LM is as 1.0 to the cube root of 0.25, or as 1.0 to 0.63. The equivalent block of width y is denoted by N.

For a 1-in. cube, $y = \left(\frac{1}{1.26} - \frac{1}{2}\right) = 0.294$ in.

These remarks apply to cubes of 1-in. side and to cubes of $\frac{1}{4}$-in. side, but not to cubes of 1/100-in. side. Such small particles are completely decomposed during one journey on the lower arc.

(270).—1-IN. CUBES IN STAGE (11).—A charge of 1-in. cubes in Stage (11) is used as an example. Referring to *Fig.* 52, the face JK of the cube will come on to the kiln lining once in every six heating cycles (or once every 7.68 minutes). It is heated for 0.215 minute, or 12.9 seconds. During the remaining period of 7.46 minutes the charge will be turned completely over 48 times [see formula (9) in Part XI]. The face JK is heated on chord for a number of short periods which

on the average total 0.199 minute (see Table XL). This intermittent heat supply is for calculation purposes spread uniformly over the 7.46 minutes, and a steady temperature difference of 56 deg. F. is thus set up between the faces JK and LM. The calculation in detail is given in Appendix II.

Since the temperature of the inner cube is 1,600 deg. F. at the centre of Stage (11), the face JK will come on to the lower arc at a temperature of 1,656 deg. F.

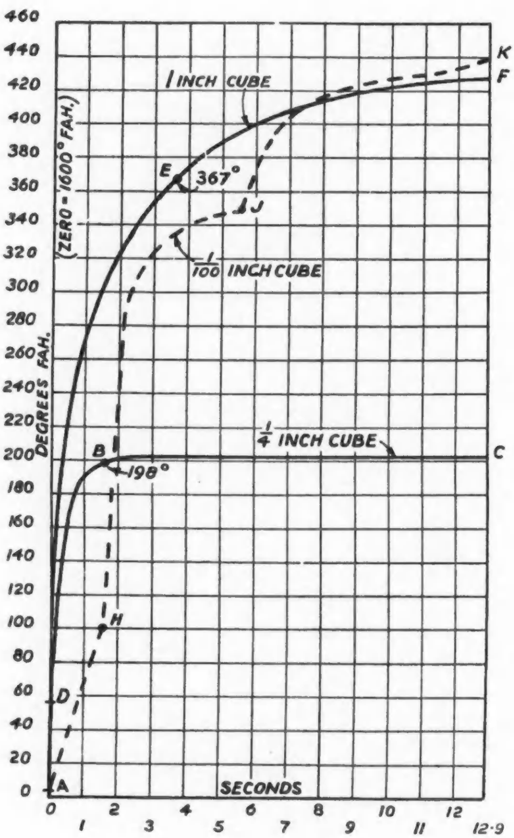


Fig. 53.

(271) The temperature rise of the face JK during heating on the lower arc is shown in *Fig.* 53 and in the curve DEF. On the graph 1,600 deg. F. is taken as zero. The face temperature rises from 56 to 428 deg. F. in 12.9 seconds, but the average value for the period is 367 deg. F. as shown at point E. Owing to

the uneven surfaces of the lining and the material lump there is little actual contact, and heat is assumed to be transferred by black body radiation qualified by emission and absorption factors of 0.90.

The average lining temperature for the period is 2,186 deg. F., thus giving an available temperature difference of 2,186 to 1,600 deg. F., or 586 deg. F. The loss of temperature difference is 367 deg. F., or 63 per cent. Further details are given in Appendix II.

(272) The heating of a ¼-in. cube on the lower arc is also shown in *Fig.* 53 and by the curve ABC. The lump loss on chord is 4 deg. F. only. When the temperature of the face JK reaches 202 deg. F. on the graph, heat is transferred across the frustrum JKML (see *Fig.* 52) as quickly as it can be supplied to the face JK from the lining, and there is no further rise in the cube surface temperature. The average loss of temperature difference throughout the heating period of 12.9 seconds is 38 per cent.

(273) The heating of a cube of 1/100-in. side has also been worked out. The entire particle reaches a temperature of 100 deg. F. on the graph in 1½ seconds, as shown by the dotted line drawn from the origin to point H, and it is then completely decomposed. The temperature rise is further indicated by the curve HJK. Particles in the second layer are completely decomposed at point J, and particles in the third layer near point K—by heat radiated from particle to particle. The average loss of temperature difference is 62 per cent.

(274) If the particle size is reduced to 1/1000-in. thus representing the charge in a dry process kiln, calculation shows that its temperature will approach the lining temperature after about 3 seconds of heating. The average loss of temperature difference throughout the heating period is 90 per cent. or thereabouts. The relatively low rate of heat transmission in dry-process kilns is thus partly explained.

(275) SUMMARY OF CALCULATIONS FOR DECOMPOSITION ZONE.—The calculations made on the effect of lump size in the decomposition zone are summarised in Table XLI. It will be seen that the charges of 6 per cent. and of 25 per cent. are used in Stages (10) and (11), the cubes being of 1/100-in., ¼-in., and 1-in. side. In this investigation the emission and absorption factor for the material has been taken at 0.90 for all lumps. Where the lump size is not used the factor is 0.90 for material on chord, and 0.75 for material on the lower arc. The factors in Table XXVI are, however, preferable for general use.

(276).—Col. (7) gives the average temperature of the lower arc, as finally obtained in each case from the schedule of heat transmission per foot run of kiln.

Col. (8) gives the lump loss on chord in degrees F. The maximum temperature difference available is that between the flame temperature of 2,450 deg. F. and the temperature of the undecomposed material as shown in Col. (6).

Col. (9) gives the average loss of temperature difference per cent. during heating on the lower arc. The maximum temperature difference available is that between the average lining temperature as given in Col. (7) and the temperature of the undecomposed material as shown in Col. (6).

TABLE XLI.

EFFECT OF LUMP SIZE IN THE DECOMPOSITION ZONE.

Section No.	Line No.	Stage No.	Charge (per cent.)	Side of cubes (in.)	Temperature of decomposed material (deg. Fah.)	Average lining temperature (lower arc) (deg. Fah.)	Average lump loss on chord (deg. Fah.)	Average lump loss on lower arc (per cent.)	B.T.U. per foot run of kiln per minute	Relative rate of heat transmission	Length of heating cycle for cube (minutes)	Time of passing stage (minutes)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	(1)			0		2,020	—	—	12,576	100.0	—	11.3
A	(2)	(10)	6	1/100	1,400	2,082	—	46	12,322	98.0	128.0	11.5
	(3)			¼		2,018	1	8	13,046	103.7	5.12	10.9
	(4)			1		2,034	12	29	12,565	99.9	1.28	11.3
	(5)			0		1,896	—	—	18,900	100.0	—	39.3
B	(6)	(10)	25	1/100	1,400	2,000	—	57	18,197	96.3	600.0	40.8
	(7)			¼		1,890	—	7	19,398	102.6	24.0	38.3
	(8)			1		1,911	3	25	18,974	100.4	6.0	39.1
	(9)			0		2,096	—	—	11,933	100.0	—	11.8
C	(10)	(11)	6	1/100	1,600	2,188	—	62	10,973	92.0	128.0	12.8
	(11)			¼		2,128	4	38	11,622	97.4	5.12	12.1
	(12)			1		2,186	56	63	10,629	89.1	1.28	13.2
	(13)			0		2,010	—	—	18,447	100.0	—	41.0
D	(14)	(11)	25	1/100	1,600	2,141	—	71	16,771	90.9	600.0	45.1
	(15)			¼		2,042	1	36	18,127	98.3	24.0	41.7
	(16)			1		2,117	18	64	16,881	91.5	6.0	44.8

Col. (10) gives the rate of heat transmission in B.T.U. per foot run of kiln per minute. The figures in lines (1), (5), (9), and (13) were obtained by the method of calculation previously used which does not depend on the actual lump size, see para. (283). These figures are used as a standard and are set down as 100 in Col. (11)..

Col. (11) shows the effect of lump size (but not the effect of charge size) on the rate of heat transfer in each section. It is seen that cubes of ¼-in. side give the best result in each case, the rate of heat transfer being nearly the same as it would be if the lump size were not specified.

With a charge of 1/100-in. cubes the falling off in the rate of heat transfer is due to the rapid temperature rise of the entire cube during heating on the lower arc, the loss of temperature difference in the decomposition zone ranging from 46 to 71 per cent. [see Col. (9)].

With a charge of 1-in. cubes the falling off is again due to the loss of temperature difference during heating on the lower arc. In this instance it is caused by the thickness of the frustrum JKML (see *Fig.* 52) through which the heat has to pass to reach the inner cube of undecomposed material.

Comparing lines (12) and (16), which relate to the centre of Stage (11), it is seen that the lump loss of the 1-in. cube on chord is 56 deg. F. for a 6 per cent. charge and 18 deg. F. for a 25 per cent. charge, the reduction being 38 deg. F.

The loss of temperature difference on the lower arc is 63 per cent. for a 6 per cent. charge and 64 per cent. for a 25 per cent. charge, the small increase being due to the longer period of heating.

The increase in the relative rate of heat transfer is 91.5 — 89.1, or 2.4 per cent. only.

Col. (12) gives the length of the heating cycle for each size of cube as calculated by formula (11) in Part XI.

Col. (13) gives the approximate time required for the material to pass through each stage. These figures are obtained in accordance with paras. (236) and (237) in Part XI, but it is here assumed that the kiln slope is suitably varied to obtain the charges of 6 per cent. and 25 per cent. as required for calculation purposes, the kiln speed remaining at one revolution per minute.

(277) LUMP LOSSES AT THE END OF THE DECOMPOSITION ZONE.—Further to illustrate the subject calculations have been made of the lump losses when only one sixty-fourth of the $CaCO_3$ remains, the position being close to the end of Stage (11). At this cross section a 1-in. cube, for instance, would have a ¼-in. cube of undecomposed material at the centre. The temperature of the latter is taken at 1,700 deg. F. The chief results are summarised in Table XLII.

Col. (3) gives the lump loss on chord in degrees F. The maximum temperature difference available in each case is 2,450 to 1,700 deg., or 750 deg. F.

Col. (4) gives the loss of temperature difference per cent. during heating on the lower arc.

Col. (5) shows the effect of the lump size (but not the effect of the charge size) on the rate of heat transfer. The rate of heat transmission at the end of the decomposition zone, as calculated by the original method, is taken at 100 for each

TABLE XLII

LUMP LOSSES AT THE END OF THE DECOMPOSITION ZONE.

Side of cube (inches)	Charge (per cent.)	Average loss of temperature difference		Relative rate of heat transmission
		On chord (deg. F.)	On lower arc (per cent.)	
¼	6	17	74	86
1	6	221	83	70
¼	25	5	75	88
1	25	80	85	80
(1)	(2)	(3)	(4)	(5)

charge. It is seen, for instance, that with a 6 per cent. charge of 1-in. cubes the rate of heat transfer in this position falls off by 30 per cent., but the loss is reduced to 20 per cent. if a charge of 25 per cent. is used.

(278) The lump loss on chord comes to a maximum at the end of the decomposition zone. When 1-in. cubes are used Table XLII shows that an increase of charge from 6 per cent. to 25 per cent. reduces the lump loss from 221 deg. F. to 80 deg. F. A large lump loss on chord in this position is undesirable since the core of the lump may not ultimately reach clinkering temperature. It is possible, however, that the last portion of the $CaCO_3$ is decomposed by heat liberated during the combination of the lime and the adjacent clay constituents.

(279) There is a Stage (12) beyond the decomposition zone in which the material is raised in temperature by external heat until the exothermic reaction is able to carry on and complete the clinkering process. The lump losses on chord are, however, small, the maximum being 36 deg F. in the case of a 1-in. cube with a 6 per cent. charge.

(280) Returning to Table XLI, it will be seen from Cols. (9) and (10) that a loss of temperature due to heating on the lower arc does not proportionately reduce the quantity of heat transmitted per foot run of kiln. There are two reasons for this, (*a*) The heat transmitted from the lower arc to the material in the decomposition zone is only about one-fourth of the total, the remainder being transmitted to the chord ; (*b*) Heat is transmitted from the lower arc to the material by radiation in accordance with the fourth-power law. Such radiation is relatively small at low temperatures, hence if the material surface temperature rises a much smaller rise in the temperature of the lower arc will enable the same quantity of heat to be transmitted.

For a similar reason the heat radiated from the flame to the upper arc, and later transferred to the material underside, is not proportionately reduced by a small rise in the lining temperature.

That is to say, a loss of temperature difference during heating on the lower arc is automatically made good to a large extent by a small rise in the lining temperature.

Summary for Decomposition Zone.

(281) GENERAL EFFECT OF LUMP SIZE.—(*a*) When the lump or particle is very small the entire lump is raised rapidly in temperature during heating on the lower arc, although the radiation from the back of the lump to adjacent particles tends to reduce it. A screen is thus formed which limits the rate at which heat can be transferred to the remainder of the charge.

(*b*) Lumps of ½-in. side or thereabouts can absorb the heat received during each journey on the lower arc without undue rise of the surface temperature. The lump loss on chord is small.

(*c*) Lumps of 1-in. side have a large lump loss due to heating on the lower arc, since the heat has to penetrate a considerable thickness of material before it is absorbed by the undecomposed core. The lump loss on chord begins to be of importance in the latter part of Stage (11).

(282) INCREASE OF CHARGE.—An increase of charge from 6 per cent. to 25 per cent. in the decomposition zone has two results, (1) It increases considerably the rate of heat transfer per square foot of lining area, and (2) It increases the time during which the material remains in the decomposition zone, thus reducing the lump loss on chord.

For lumps of ¼-in. cube or thereabouts, which would represent a normal wet-process kiln charge, Table XLI shows that a charge of 6 per cent. allows the material to remain in the decomposition zone for a sufficient length of time. For lumps of about 1-in. side a charge of 6 per cent. does not appear to be sufficient. For cubes of 1/100-in. side Table XLI shows that a 6 per cent. charge is to a small extent preferable.

Calculating the Rate of Heat Transmission per Foot Run of Kiln.

(283) The original method of calculation as used in Parts VI, VII, and VIII in connection with the 400-ft. kiln neglected the lump loss on chord, and allowed for the lump loss on the lower arc by reducing the emission and absorption factor of the material to 0.75 in all cases [see para. (52) in Part III and Table XXVI in Part VIII.]

The rates of heat transfer in lines (1), (5), (9), and (13) of Table XLI were calculated in this manner. Col. (11) shows that the same result would be nearly obtained by treating the material lumps as cubes of ¼-in. side—see lines (3), (7), (11), and (15). Cubes of ¼-in. side may be taken as representative of the charge in a wet-process kiln as soon as the material is dry on the surface. The agreement between the two methods of calculation also extends to Stages (6), (7), (8), and (9) in which the material is raised in temperature from 212 to 1,300 deg. F.

In the drying zone the original method of calculation is confirmed by the investigation reported in Part XI, although further experiments relating to the unit rates of heat transfer in this part of the kiln are desirable. That is to say, the original method of calculation as used in Parts VI, VII, and VIII is suitable when applied to a normal wet-process kiln in which the lump size ranges from $\frac{1}{16}$-in. to ⅜-in. or thereabouts. Provision has, however, been made for calculating the rate of heat transfer when lumps of a larger size are used. This may happen when the rotary kiln is applied to other industries.

Note on Gas Radiation.

(284) Experiments now in progress tend to show that the heat radiated from the gases H_2O, and CO_2, as given in Tables II and III in Part II, may be underestimated. Should this be the case it is probable that there are agencies, in addition to the emission and absorption factors mentioned in Table XXVI, which reduce the rate at which heat can be transmitted by radiation from the hot gases to the lining and to the charge in a rotary kiln. An increase in the intensity of gas radiation would not alter the total length of a kiln as now calculated for any given output and exit-gas temperature, since the present method of calculation gives results which are in agreement with results obtained by testing a large number of rotary kilns. It is possible, however, that some alteration would be made in the relative lengths of the various stages.

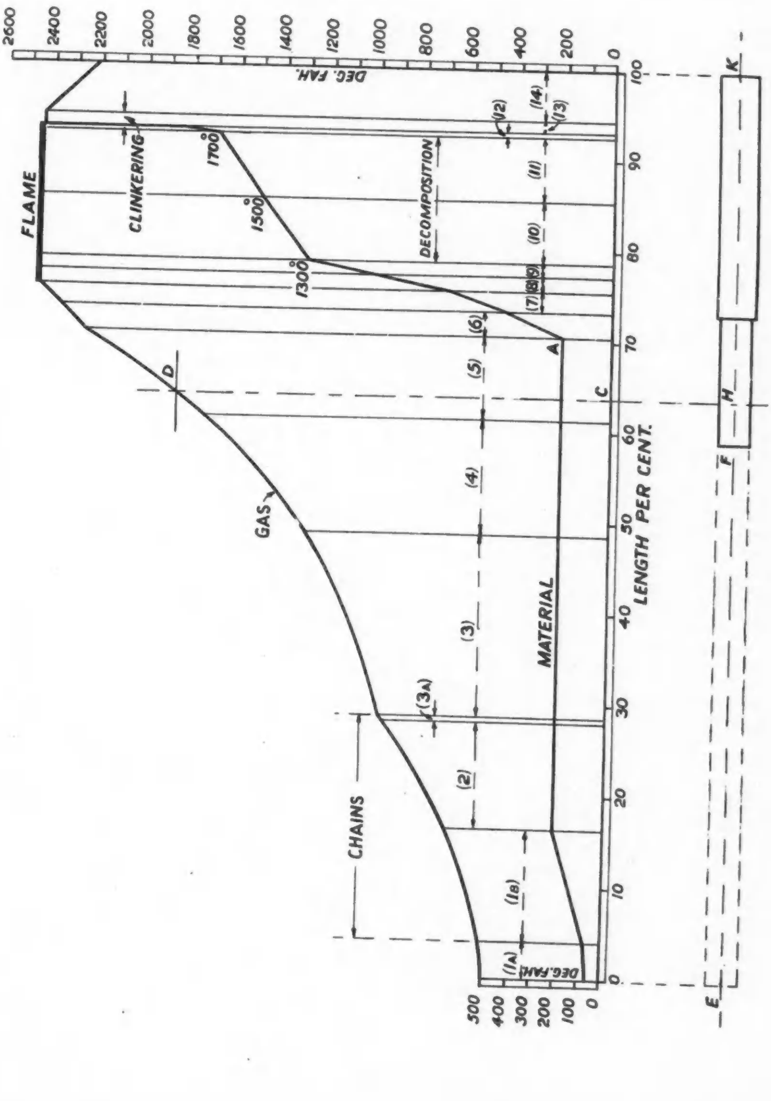
An Improvement in Kiln Design.

(285) The calculations made on the 200-ft. kiln (see *Fig.* 17, Part V, October, 1933) and on the 400-ft. kiln (see *Fig.* 28, Part VIII, May, 1934) show in each case that about 70 per cent. of the kiln length is devoted to drying the slurry. The 200-ft. kiln was not provided with chains or slurry lifters, and the exit-gas temperature was 950 deg. F. With chains, the 400-ft. kiln reduced the exit-gas temperature to 500 deg. F., but the proportion required for drying was substantially the same.

A plain cylinder of 8 to 10 ft. diameter lined with firebrick is unsuitable for slurry drying, especially near the feed end, when it is desired to reduce the temperature of the exit gases to about 250 deg. F. At this temperature the radiation from the H_2O and CO_2 is nearly zero, and it cannot be increased by any device. The rate of heat transfer by convection may, however, be greatly augmented by splitting the gas column into thin streams to overcome its want of conductivity, and by increasing the gas velocity. Well-designed independent slurry driers arranged on these lines are now available, and reduce the slurry moisture from about 40 to 12 per cent.

(286) Suppose a slurry drier of this class is applied to the 400-ft. kiln. The moisture in the slurry, originally 112 lb. per 100 lb. of clinker [see para. (111)] would be reduced to 20.6 lb. per 100 lb. of clinker, that is to less than one-fifth, before entering the kiln.

Part of the temperature diagram for the 400-ft. kiln is here reproduced (*Fig.* 54). The temperature of the slurry is raised to 212 deg. F. at the end of Stage (1B) and it is completely dried at the end of Stage (5), see point " A " on diagram. The slurry moisture will be reduced to 12 per cent. in the position indicated by the ordinate HCD, which is at 64 per cent. of the length of the kiln. The gas temperature (see point D) is 1,860 deg. F. as shown by the scale on the right. As a first approximation we may remove 64 per cent. of the kiln length and apply a slurry drier in its place. The exit gases will fall from 500 to 250 deg. F. or less, and due to this the standard coal consumption will be reduced from 24.5 per cent. to 22.0 per cent. or somewhat less. The coal feed could be reduced in this ratio, but it would be preferable to keep it as before and to increase the kiln output, in this case by 11 per cent.


FLAME
CLINKERING
DECOMPOSITION
GAS
MATERIAL
CHAINS
LENGTH PER CENT.
DEG. FAH.
DEG. FAH.
1300°
1500°
1700°
A
C
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0 10 20 30 40 50 60 70 80 90 100
0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600
0 100 200 300 400 500

Fig. 54.

(287) To deal with the increased output the surface area of the rotary kiln portion will be increased by approximately 11 per cent., so that referring to the lower diagram in *Fig.* 54 its length will be increased from KH to KF. The portion EF to be removed is now 59 per cent. of the kiln length.

It is found by calculation that the gas temperature entering the slurry drier should be approximately 1,610 deg. F. This initial temperature is sufficient to deal with the increased output when the exit-gas temperature is reduced to 250 deg. F. If *Fig.* 54 had been drawn originally for an exit-gas temperature of 250 deg. F. the length of kiln to be removed and the gas temperature at the dividing plane would be at once apparent.

(288) It is clear that rotary kilns 400 to 500 ft. in length and provided with chains are not likely to be installed in the future, since it is obviously desirable to replace them by kilns of about half that length working in conjunction with independent slurry driers.

It would be of advantage to have a charge larger than 6 per cent. in the rotary kiln portion. This could be done by reducing the slope, the shell being of the same diameter throughout. An improved rate of heat transmission per square foot of lining area would be thus obtained.

(*To be concluded.*)

The Influence of Catalysts in the Production of High-strength Cements.

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ALL investigations seem to show that good clinkering is of outstanding importance in the production of good quality cements, but no satisfactory test has been devised for ascertaining when the clinkering process has been carried far enough. Indeed it is not very clear as to what is actually aimed at in the process. All that can be said is that the heating should stop at a point short of fusion, but that it should be sufficient to produce complete combination during the passage of the material through the kiln. Kühl[30] suggests that a dense clinker should be aimed at and that this can be attained either by intensive burning or by the introduction of fluxes in an attempt to clinker at a lower temperature. In order to arrive at perfect clinkering the three main factors are burning temperature, time of exposure to maximum temperature, and rate of cooling. Factors influencing the burning temperature will be dealt with later under the subject of fluxes.

Kühl[30] states that investigations indicate that rapid cooling of the clinker improves the hardening properties of the cement. He explains this as being analogous to the effect of cooling on molten slags. In this way it seems desirable to produce in the clinker a high proportion of glass, which upon grinding would produce material of a greater reactivity with water. Since Portland cement clinker is not molten when it leaves the kiln the amount of glass that can be obtained is much less than is obtained in the case of slags. Moreover rapid cooling by quenching in water or salt solutions tends to give a light coloured clinker which on grinding gives a yellowish cement. The main drawback to quenching the clinker seems to be that it spoils the colour, tending to give a cement having an underburned appearance. The practical difficulties of rapid air cooling of clinker have not yet been overcome, since the introduction of large quantities of cool air into the kiln leads to increased coal consumption in maintaining the temperature of the kiln.

A large variety of fluxes has been tried with a view to improving the quality of cement and reducing fuel consumption. Of these alumina and iron oxide have already been dealt with elsewhere.* Good results have been obtained with the addition of fluorspar. Guttmann and Biehl[1] found that the addition of 1 to 3 per cent. of fluorspar to the raw mix lowers the clinkering temperature and also gives a better combination of the ingredients, producing a rapid-hardening cement. This is confirmed by Becker.[2] Kühl[3] says that the addition of fluorspar to the raw mix produces no detrimental physical effect and has no effect upon the strength of the cement at 28 days. He found that a stable, sound clinker could be produced at 1,430 deg. C., at which temperature no loss of fluorine occurs. If the clinkering temperature is above this point fluorine escapes in the flue gases,

*See "Chemical Considerations underlying the manufacture of Portland Cement," *Cement and Cement Manufacture*, September, 1935.

and at 1,600 deg. C. the clinker is devoid of fluorine. Muller[4] states that fluorspar additions to the slurry tend to shorten the life of aluminous kiln linings, which tend to absorb fluorine and alkali immediately behind the clinkering zone. There is in the lining an exchange of alumina for fluorine and alkalis, for the content of the former drops at the expense of additions of the latter and the life of the lining is thereby shortened.

Among other catalysts which have been used to increase the fluxing of cement clinker, borax and alkalis have received much attention. Although these substances undoubtedly help to produce a more vitreous clinker, no marked improvement in strength seems to have resulted. According to Nagai[5] the addition of 0.5 to 1 per cent. of borax reduces the absolute strength, although it diminishes any deterioration on water curing and also prevents dusting of the clinker. Hansen and Bogue[6] show that the addition of alkalis (potash and soda) does not catalyse the reactions of clinker formation. Above 1 per cent. of alkali begins to be detrimental to the production of sound clinker at the ordinary burning temperatures. Alkali additions are also to be discouraged on the ground that high alkali cements effloresce badly.

Apart from any possibility of catalysing the formation of the necessary clinker compounds, attempts have been made to increase the rate of hardening by the addition of various materials to the cement. Catalysts have been added by grinding them with the clinker or by adding them to the gauging water.

It is well known that gypsum, in addition to regulating the set, increases the strength of the cement. Many other substances have been tried, among which calcium chloride appears to have given the best results. Achsharumov[7] carried out tests by grinding clinker with and without 2 per cent. calcium chloride, and found that chloride not only accelerated the hardening, but also the rate of increase in strength. He recommends the use of cement ground with calcium chloride for sea work. He proposes that the clinker should be sprayed with 0.25 to 1 per cent. solutions of fused calcium chloride before grinding. Bauer[8] found that with ordinary Portland cement the addition of small percentages of calcium chloride increases early strength, but has little or no effect on strength after longer periods of hardening. With rapid-hardening Portland cement similar percentages of calcium chloride produce a very marked increase at 24 hours and this persists at least to 28 days. Abrams[31] showed that calcium chloride and admixtures containing calcium chloride when used within the limits of 1 to 2 per cent. chlorine gave increased strength to concrete. Beyond 3 per cent. of chlorine further additions produce a reduction in strength compared with similar concrete without admixture. He concluded that no advantage is gained for percentages of calcium chloride greater than 2 to 3 per cent. of the weight of cement. This amount when used in mixes of about one in five and of consistencies suitable for constructional work showed an increase in compressive strength of 200 lb. per square inch, which was practically constant at ages of two days to three years. For richer mixes and drier consistencies the strength increase was greater. Spiegelberg[32] found that the effect of calcium chloride varies with the composition and general properties of the cement ; he observed little or no increase

in tensile strength. Moreover he found that the increase in compressive strength was more pronounced with rotary kiln cements than with any other type.

Platzmann[33] also made tests with calcium chloride admixtures from 1 to 5 per cent. Throughout the tests a certain reduction in the time of setting was observed but in no case was there a change to quick setting properties. Although an increase in compressive strength was obtained in all cases without any increase in tensile strength, a slight retrogression both in compressive and tensile strengths was observed at later ages. He attributes the effect of calcium chloride to two factors: (1) The strongly hygroscopic properties of calcium chloride prevent the formation of hair shrinkage cracks in the specimens, by absorbing moisture from the air and thus keeping the cement from too rapid drying during the first period of hardening. This, he maintains, would explain the gain in compressive strength up to 28 days; (2) The subsequent decrease in strength compared with that of specimens without admixture could be explained by the destructive action of calcium chloride at later ages, when, as a soluble chloride, it acts in the same way as sulphates, producing instead of calcium sulphoaluminate a similar chloro-aluminate. Both Killig[34] and Platzmann[33] have shown that at ordinary temperatures calcium chloride reacts with the cement actively enough to accelerate crystal growth during setting, accompanied with a considerable rise in temperature. There can be little doubt that this increased reaction speed is based on the greater solubility of lime in calcium chloride solutions.

Levens[9] showed that, in addition to improving the strength, admixture of 2 per cent. calcium chloride solution improved the texture of the concrete. The shrinkage is, however, about 85 per cent. greater than in the case of plain concrete. The maximum shrinkage in concrete results from the addition of 4 per cent. calcium chloride to 1 : 2 : 4 concrete, it being 150 per cent. greater than with plain concrete after 21 days. Although the addition of small quantities of calcium chloride may not be objectionable for some work its use is not advisable where, as is often the case, shrinkage is an important matter.

Surface dressing of concrete with calcium chloride has been tried, particularly in America. Although calcium chloride hastens the setting of concrete it is in no sense a real protective against frost, and this surface application only enables the concrete to be used much sooner than usual. Clemmer and Burggraf, of the Illinois Highways Division,[10] found that specimens of concrete could be cured most effectively by the application of 3 lb. of dry calcium chloride per square yard to the surface after it had thoroughly set. They found that the strength produced at the end of 14 days was practically equal to the strength of specimens without treatment at the age of 30 days. They also found that the calcium chloride could be removed 24 hours after application without affecting the curing of the concrete. Dry calcium chloride resulted in much harder concrete at the end of 28 days than calcium chloride in solution; lumps of calcium chloride are detrimental, and the Illinois Highway Authority specifies that flakes should be used. Application of excessive quantities of calcium chloride produces a puffing-up of the surface. The value of calcium chloride as a curing agent is almost entirely

due to its hygroscopic properties. Although the calcium chloride may not obtain sufficient moisture from the air to satisfy this property its presence on the top of the concrete draws moisture to the surface, leaving minute channels through which calcium chloride solution can penetrate the surface, thus giving access to more cement particles and causing more complete hydration in a shorter time. This quick hydration and decomposition of the lime compounds of the cement particles on the surface produce an impervious layer which prevents the drying out of the concrete. It is also probable that the viscous film of calcium chloride which is formed on the surface offers a protection against the drying effect of the air.

The Building Research Board[11] question the use of calcium chloride on the ground of various uncertainties, such as (1) risk of harmful impurities, e.g., bleaching powder ; (2) tendency to corrosion of reinforcement unless the concrete is very dense ; (3) variability of behaviour with different brands of cement. Although there is evidence that calcium chloride increases the strength of concrete in many cases, the uncertainty of its action is such that, if risks of failure are to be avoided, a complete series of tests is necessary with the materials to be used under the conditions likely to exist on the work before the safe conditions for the addition of calcium chloride can be defined. The advantage of calcium chloride attributed to its hygroscopic nature, i.e., causing concrete containing it to retain moisture and thus diminish shrinkage stresses, could be equally well obtained by curing in a damp atmosphere.

Grün[12] found that additions of the chlorides of Ca, Ba, Al, or ferric iron to the water used in making concrete mixtures appreciably increase the rate of setting and the early tensile and compressive strengths. He considers that this is probably due to the formation of calcium chloride by double decomposition in every case.

Kühl[35] made a comprehensive investigation into the catalytic effect of various metallic chlorides and found that the only ones which gave increased strength to the cement were those of Li, Na, K, ammonium, Ca, Sr, Ba, Co, Al and Fe(ic). Reduction in strength resulted from additions of Mn, Sn, Zn, Cu, and particularly Pb chlorides. This seems to indicate that the chlorides of the so-called heavy metals are definitely injurious.

Although the addition of sodium chloride up to 1 per cent. quickens the set and improves the hardening of concrete, it appears to be liable to cause efflorescence. The Building Research Board[11] quote cases in which serious diminution in strength due to the use of NaCl has resulted, and it is considered that it should not be used in cement for reinforced construction.

Abrams[36] showed that magnesium chloride when used to the extent of 1 to 2 per cent. in concrete caused a slight increase in 2-day and 7-day tests, but additions above 2 per cent. produced a reduction in strength practically in proportion to the amount of magnesium chloride added.

Pitt[13] states that calcium oxychloride is preferable to calcium chloride as an accelerator for Portland cement for reasons of cost and manipulation. A 2 per

cent. admixture of calcium oxychloride gave the greatest increase in early strength together with a decided improvement at later ages. Catlett[14] patented the use of 1 to 10 per cent. calcium oxychloride additions to Portland cement for hastening the development of strength. He suggested mixing the cement and oxychloride in the dry state, and proposed to prepare the oxychloride by the interaction of 100 parts of ground CaO with 75 parts calcium chloride and 50 parts water.

At various times sodium salts other than chloride have been tried as catalysts in the hardening process of concrete mixtures. Sodium carbonate has frequently been suggested and its use has been the subject of many patents, particularly in conjunction with additions of aluminium sulphate. Hovermann[15] has patented a mixture for obtaining a rapid-hardening product, impermeable to water under either high or low pressure. It consists of 100 parts cement, 2 to 4.5 parts sodium carbonate and 1 to 1.5 parts aluminium sulphate. According to Gonell,[16] although the early strength of cement may be improved by additions of sodium carbonate, the strength at later dates falls rather below normal.

Both sodium bisulphite and bisulphate have been advocated for improving the early strength of concrete. An Austrian patent[17] suggests the addition of a mixture of chloride and acid sulphate, the total salts added not exceeding 5 per cent. of the weight of the cement. These salts can be added to the cement either before or after grinding, or alternatively they can be added, wholly or in part, to the gauging water. It is claimed that the initial strength is thereby increased and surface disintegration avoided. Luftschitz,[18] with 0.5 1, 2 and 4 per cent. sodium bisulphite added to the cement, made test pieces and broke them after 24 hours, 7 days, and 28 days. He found the effect of adding the salt was on the whole to reduce the strength, compression strengths being reduced in every case.

Kallauner[19] studied the influence of sodium phosphate and borate solutions upon the strength of cement mortars. He found that test pieces mixed with and stored in sodium phosphate solution showed a greater strength both in compression and tension up to 90 days than when pure water was used. The increase is greater with increase in the concentration of phosphate ions in solution. An insoluble calcium phosphate is formed which quickens the set, and prevents the solution of calcium hydroxide giving hard dense specimens on storage. Sodium borate, on the other hand, has very little influence on strength. There is danger of formation of calcium borate which fills the pores and also absorbs water of crystallisation with an increase in volume, so that if a high concentration of sodium borate is used the strength decreases.

Meyer[20] found that addition of sodium silicate to the mixing water quickens the setting of concrete mixes; the final hardening, however, never attains as much strength as normal concrete. Briquettes made with water and immersed in 10 per cent. sodium silicate solution after 24 hours have a greater strength than similar briquettes immersed in water alone. Meyer also points out that an aqueous solution of sodium silicate can be used as a filler and prevents dusting of concrete floors.

Although additions of hydrated lime do not materially improve the early strength of concrete, various workers have found that its presence considerably

improves the manipulation of the wet mixture. Spackman[21] recommends additions of hydrated lime up to 10 per cent. Mortars are in these cases more plastic and impermeable and, although the maximum shrinkage and expansion are increased, early shrinkage due to the draining off of the surplus water is reduced. Morrison[22] says that calcium hydroxide is especially valuable in absorbing and holding the excess water and so preventing too rapid drying out. He states that the set is retarded by the addition of calcium hydroxide. Edwards[23] recommends 10 to 15 per cent. additions of hydrated lime to concrete mixes for roads. This causes the mix to flow more readily and prevents the tendency towards segregation of the larger particles. Many cases of preventing efflorescence of concrete structures have been attributed to the addition of hydrated lime. Probably the reduction in efflorescence was due to reduced permeability obtained with the more workable mixes produced by the addition of hydrated lime. Scholfield and Stinchfield[24] consider that hydrated lime added to cement has not the advantages that previous workers claim for it. The work of Ashton[25] produced some rather astonishing results in view of previous work. He reported tests on concrete with additions of 5, 10 and 15 per cent. of hydrated lime. His results showed that (1) as the proportion of hydrated lime was increased more difficulty was experienced in getting the material into the test forms ; (2) the addition of hydrated lime did not increase the flowability compared with concretes with the same water content ; (3) the addition prevented segregation, and this was the greatest gain that could be obtained by the use of hydrated lime.

Addition of slag to cement has been recommended by some workers. Deny and Lewis[26] state that addition of slag, low in sulphur, to the extent of 30 per cent. of the weight of cement increases the early strength. West,[27] however, found that good Portland cement is not improved by the addition of slag although a poor cement may be. Moreover, addition of slag slows the set.

Trass, spent shale, and diatomaceous earth have also been tried in an attempt to improve the early strength and rapid hardening properties of Portland cement. According to Grün[28] the addition, by simple mixing, of up to 40 per cent. of trass increases strength and resistance to wear. Nagai[29] states that the strength of Portland cement mixtures containing various proportions of spent shale is considerably greater than that of ordinary Portland cement. In U.S. patent No. 1,082,684/1913, Duryee makes high-strength cement by grinding Portland cement with 10 to 15 per cent. of diatomaceous earth with or without a small proportion of hydrated lime. The addition of these materials, containing silica in a moderately reactive form, would no doubt assist in combining any free lime present either in the original cement or liberated in the form of hydrated lime during setting. Although this would not necessarily improve the early strength it would give a less permeable concrete and reduce efflorescence due to free hydrated lime.

Improvements in the surface hardness of concrete structures, in order to increase their resistance to wear, have also received attention. A series of patents in the United States indicates the direction in which such improvements have been attempted. Flesheim, in U.S. patent No. 1,113,112/1914, hardens the

surface of concrete by applying to the surface before it has set a layer of dry cement mixed with finely divided iron, rubbing the mixture into the surface so as to produce a burnished finish and keeping it moist until the concrete has thoroughly set and hardened. Malderman, in U.S. patent No. 1,113,355/1914, also incorporates fine iron powder coated with a film of Fe_3O_4 to render it adherent and prevent further oxidation when the concrete is set.

In conclusion, if we exclude gypsum, it can be said from a practical point of view that no very great improvement has yet been made in the early strength of Portland cement by the addition of catalysts to the cement after grinding. Certain substances give slight improvement, though in most cases this is due to remedying a defect either in the original cement or in the concrete made therefrom. The present writers consider that investigation of the influence of catalysts upon the process of clinkering, i.e., additions to the raw materials, promises far better results than additions to a cement obtained from comparatively poorly clinkered material. One requirement of good clinkering appears to be a dense vitreous material ; addition of fluxes to the raw material which will produce this without increasing the difficulty of burning is one of the most urgent subjects for investigation.

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Relationship of Mill Charge to Surface Area of Cement.

IN a recent number of "Rock Products," Mr. W. R. Chandler, Chief Chemist of the Idaho Portland Cement Co., gives the results of an investigation into the effect of varying mill charges upon the quality of Portland cement as expressed in the surface area exposed. The idea, states the author, is not new, but a new interpretation can be given it when it is remembered that the usual method of arriving at increased fineness has been to increase the time of grinding using the already existing charge of media. In addition, it brings into play later conceptions of fineness as expressed by surface area. The design and construction of apparatus for surface area determination was a secondary but necessary consideration.

A laboratory ball mill, 18 in. by 24 in., running at 43 revolutions per minute was used. This was constantly loaded with 550 lb. of media, which filled it to a point 1½ in. below its centre line. A revolution counter was fitted to the mill, and for each charge of cement the mill was given 850 revolutions. One thousand revolutions were necessary to empty the mill of cement. There is some disagreement of opinion as to the advisability of using a laboratory mill for estimating probable grinding results to be obtained in a full size mill, and the results obtained are to be accepted only as comparative with each other. No definite predictions can be made as to comparative results which might be expected from a commercial mill. It is, however, reasonable and safe to assume that useful results would be obtained from following the guidance pointed out by laboratory deductions.

Particle Size Distribution.

Investigators are not fully agreed upon the size distribution most desirable in Portland cement. The statement is frequently made that any particle smaller than 10 microns will hydrate almost immediately, even while being gauged, thereby destroying the effectiveness of a large percentage of the potential strength of the concrete. Other investigators believe that grading of sizes will produce the best results. Later theories prefer a classification of fineness defined by the surface area of the particles of cement ; aiming at the maximum area exposed within an economic cost of production. This must be modified when low-heat or special cements are under consideration. Certainly the conception of fineness as expressed by a proportion passing a 200-mesh sieve does not give a true idea of the effectiveness of grinding. The consensus of opinion is in favour of finer grinding, not necessarily that the proportion remaining on a 200-mesh sieve shall be lowered, but that the proportion of 10-micron material shall be raised. When it is considered that the ratio of area factors of minus 10-micron material to plus 10- minus 20-micron is three to one, one can readily apprcciate the large difference made in surface area by any increase in minus 10-micron material.

Apparatus Used for Surface Area Determinations.

The apparatus is of the sedimentation type, following the principle of Stokes' law for falling bodies. Kerosene was used as the liquid medium, enough being supplied so that no additions were necessary during the experiments. The selection of sizes, as shown in the table, was made on the assumption that a greater number of fractions would have a tendency toward greater accuracy of surface area results.

An examination of Stokes' formula shows that the viscosity of the liquid through which the particles fall is an important factor. Inasmuch as no reliable viscosity values for kerosene could be found, determinations were made in the laboratory by an Ostwald viscometer pipette. At least three viscosity readings were made at intervals of 2 deg., starting at 17 deg. C. and running to 31 deg. C. The graph so obtained proved to be a straight line, and it was considered reasonably safe to continue the line into temperature ranges not determined in the sedimentation apparatus but at which operating temperatures might exist. To simplify the calculations the cement specific gravity for the various samples was considered to be the same, i.e. 3.032. The variation of any one sample from this figure was small.

Use of Apparatus.

When using the apparatus, a sample of cement was dispersed in the settling tube and agitated with dry air. The time of settling in seconds was determined by the formula. Inasmuch as temperature of the settling medium is a function of viscosity, it was necessary to provide a means of determining this time element for any reasonable room temperature. This was accomplished by plotting a separate graph for each micron size to be determined, by which the settling time in seconds could be directly read from the graph for any temperature. By installing a thermometer through the top of the sedimentation tube, the time of settling could be varied at will for each settling period to hold true as the kerosene temperature might vary. A minimum of rubber connections was aimed at on account of the action of kerosene on rubber. This was made by using a burette tube, with a 6-mm. glass stop-cock delivering each charge of kerosene to the sedimentation tube, and an all-glass siphon delivering to the burette.

The method of procedure is as follows: Two grams of the cement, which has been screened through a 20-mesh sieve, are weighed into a 250-ml. beaker. To this are added about 50 ml. of kerosene, and the cement is dispersed by gentle stirring. With the pinch-cock closed in the discharge tube, and the stopper in the bottom of the cone in place, all the cement and kerosene is rinsed into the top of the sedimentation tube with a kerosene wash bottle. The sides of the tube are washed down. The tube is now set in place, and kerosene run in from the burette until the liquid meniscus reaches the top level mark. Air agitation is commenced through the drying bottle until the cement is thoroughly dispersed throughout the tube. When the agitation has been stopped, and as soon as the last air bubbles have reached the top of the liquid, the stop-watch is started, temperature reading made, and from the graph for the size being determined is

read the number of seconds the mixture is to stand. At the end of this time the pinch-cock on the side discharge tube is opened and the liquid above the discharge level is run into a beaker. This carries with it the cement which, in the time allotted, has not had time to settle past the discharge level. The tube is now refilled with kerosene, agitated with air, and the process repeated until the liquid above the discharge level appears to be free of suspended material at the end of the settling time. Eleven repetitions were found necessary to clear the solution. After the last settling and discharge have been completed a beaker is placed

TABLE I.

MILL CHARGES. COMPOSITION OF GRINDING CHARGE IN PERCENTAGES. SIZE MEDIA BY WEIGHT.

Sample.	1¼ in.	−1¼ in. +1 in.	−1 in. +¾ in.	−¾ in. +½ in.	−½ in. +⅜ in.	−⅜ in. +¼ in.	Per cent. voids in charge.
A per cent. ..	100.0	—	—	—	—	—	40.00
B ,, ..	90.0	7.5	2.5	—	—	—	36.09
C ,, ..	80.0	10.0	7.5	2.5	—	—	37.69
D ,, ..	70.0	15.0	10.0	3.0	2.0	—	36.95
E ,, ..	60.0	20.0	12.5	4.5	2.0	1.0	36.08
F ,, ..	40.0	30.0	20.0	5.0	5.0	—	37.29
G ,, ..	30.0	30.0	20.0	10.0	10.0	—	36.95
H ,, ..	20.0	12.5	30.0	25.0	12.5	—	37.69
I ,, ..	15.0	7.5	30.0	35.0	12.5	—	37.89

TABLE II.

PHYSICAL CHARACTERISTICS OF CEMENT SAMPLES.

Cement sample.	Normal con-sistency.	Setting Time.		Tensile strength.	
		Initial.	Final.	7 days.	28 days.
A	24.0	1 : 55	3 : 55	345	377
B	24.1	1 : 40	4 : 00	327	367
C	24.7	1 : 50	4 : 15	380	382
D	25.0	2 : 10	4 : 00	357	393
E	24.7	2 : 40	4 : 50	367	377
F	25.3	2 : 20	4 : 10	358	375
G	25.8	1 : 50	4 : 00	368	370
H	26.6	2 : 00	4 : 00	395	395
I	26.5	2 : 40	5 : 20	407	420

under the cone, the stopper drawn, and the cone and tube washed into the beaker with kerosene. The residue now in the beaker is filtered through a tared alundum crucible, and finally washed with petroleum ether. After drying, the material collected is weighed in the crucible, and its percentage of the original sample calculated. This is the material above the size which has already been discharged through the side tube. As each successive size is determined the various fractions are readily calculated.

The computation of the surface area of any fraction from the data obtained is made by multiplying the fractional percentage, expressed in parts per hundred,

by the reciprocal of the average particle size of the fraction in microns. This figure in turn is multiplied by the constant 600. The sum of the result of these computations gives the number of square centimetres area per cubic centimetre of cement. This is divided by the specific gravity of the cement to arrive at the number of square centimetres per gram of cement.

Ball Mill Charges of Grinding Media.

In selecting ball charges for the laboratory mill no definite rule was followed. As may be seen from Table I, a diminishing scale was applied to the large sizes and a correspondingly increasing scale to the smaller sizes. The media consisted of 1¼ in. Concavex, a quantity of worn balls of the same kind, and a few small round balls. These were separated into various sizes until enough of each was available for the calculated charges. Each mill charge was then made up on a percentage weight basis.

TABLE III.

DISTRIBUTION OF MICRON SIZES BY PERCENTAGE WEIGHT OF SAMPLE.

Sample.	0-10 m.	10-20m.	20-30m.	30-40m.	40-50m.	50-60m.	60-74m.	74-147m.	147 m.
A	33.89	10.18	6.79	8.54	5.83	5.54	9.13	13.73	6.37
B	33.56	15.00	8.37	6.32	5.63	3.64	10.33	12.11	5.04
C	33.39	18.97	9.31	5.25	5.30	3.66	9.72	10.24	4.16
D	33.45	17.59	11.69	3.35	5.95	4.10	10.13	10.03	3.72
E	34.06	13.57	11.26	6.71	5.87	5.43	9.45	10.18	3.47
F	38.63	12.08	11.55	7.27	4.46	3.75	10.66	8.81	2.79
G	36.75	16.69	10.10	10.00	4.08	3.68	9.21	7.11	2.39
H	40.18	19.36	10.66	7.79	4.84	2.49	7.53	4.69	2.46
I	39.26	20.12	12.46	6.86	4.96	3.03	5.81	4.99	2.51
Sample.	A	B	C	D	E	F	G	H	I
Sq. cm./c.c. ..	5,103	5,229	5,349	5,340	5,306	5,775	5,716	6,179	6,121
Sp. Gr. ..	3.018	3.030	3.023	3.032	3.038	3.038	3.046	3.033	3.033
Sq. cm./gr. ..	1,691	1,725	1,769	1,761	1,746	1,901	1,876	2,037	2,018

A sufficient quantity of normal clinker was set aside to complete all the tests, but it was not considered necessary to make a chemical analysis of it. However, the analysis of clinker produced by the mill averages as to its major components 51 per cent. C_3S, 23 per cent. C_2S, and 13 per cent. C_3A. All this clinker was reduced through a laboratory crusher until its size approximated the same as that entering the finishing compartment of a commercial mill. It was also thoroughly mixed before removing any for grinding. Each grinding charge consisted of 550 lb. of media, 18 lb. of clinker, and 14 oz. of gypsum. Three batches of cement were made from each sample resulting in the production of approximately 55 lb. of cement for each sample. Each batch was ground with 850 revolutions in the closed mill and discharged in 1,000 revolutions.

Table II illustrates how the increased surface area affects the physical properties of the cement. An appreciable change in normal consistency is noticeable, and the samples may be clearly grouped into three classifications. While it is commonly believed that an increase in fineness, as measured with the 200-mesh sieve, has no effect upon normal consistency, it must be evident that a change in

surface area does affect normal consistency. There do not appear to be sufficient differences in setting times to warrant a definite statement. Setting times appear to lengthen as surface area increases. On the other hand, this might be a result of increased mixing water. Table III shows the size distribution of the various samples.

Details of Apparatus.

Fig. 1 is a sectional sketch of the sedimentation tube and connections (not to scale), and is shown to indicate the construction of the discharge take-off. The object is to remove the liquid above this point as rapidly as possible without causing eddy currents below the horizontal plane which might pick up material

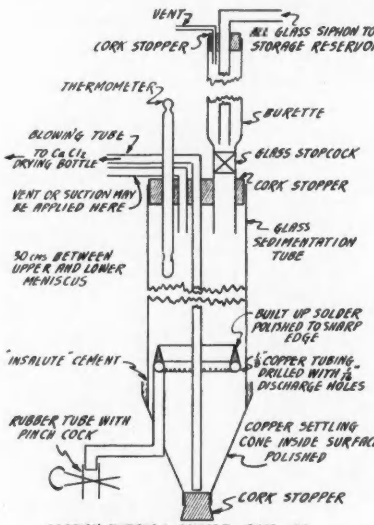

Fig. 1.—Sectional View of Sedimentation Tube and Connections.

that has already settled below. The sharp tapered upper edge of the circular tube is designed to allow settling particles to pass into the cone. Even so, it is wise to tap the tube gently a few seconds before discharging it, in order to dislodge any particles which may remain on the slopes of the taper. The settling cone is designed to bring all settled particles close to the mouth of the air-agitation tube so that they will be stirred back into the solution when the air is forced through. The bottom cork should fit snugly, within the cone, so that the cement will not lodge in the corners and fail to be redistributed throughout the tube at each agitation. The least necessary number of agitations may be effected by designing the discharge point as low as possible in the tube. " Insalute " makes a satisfactory cementing medium between glass and metal so long as it is not in contact with water.

Conclusions.

The conclusions reached indicate that a radica change in the finish compartment mill charge from 100 per cent. $1\frac{1}{4}$ in. Concavex to a mixture of smaller sizes will result in improved quality cement. On the other hand, if the present quality is sufficiently good, this standard of quality may be held at this same level by reducing the time of grinding. In other words, an increase in mill production might be expected from a redesign of mill charge. For their assistance and suggestions, acknowledgment is made to A. W. Hooton and C. R. Green.

MR. R. H. HARRY STANGER, of the Testing Works and Chemical Laboratories, Broadway House, Tothill Street, S.W.1, informs us that he has taken into partnership his son, Mr. C. Harry Stanger, who has been his chief assistant for some time.

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